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ABSTRACT

This report summarizes the research results and provides a reference. The basic question addressed was, "Is performance on multi-component tasks predicted by performance on the individual components performed separately?" In the first series of experiments, a dual task involving memory and verbal processing components to predict a psycholmetric measure of verbal ability was used. The two types of measures predicted performance on the criterion verbal ability measure equally well. In the second experimental series, ability to detect visual and auditory targets in single channel, focused attention, and divided attention conditions were compared. Performance in the single channel conditions predicted performance in focused and divided attention conditions. Performance on a simple secondary task executed during an easy primary version of the primary task. Dual task performance provided information unavailable from the single task counterpart. The theoretical basis of this research was provided by a "general resource" theory of attention, in which all mental processes are seen as drawing on the same pool of attentional capacity. The Production Activation Model, a more explicit model of inter-task interference, was developed. (Author/DWH)

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Individual Differences in Dual Task Performance

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University of Washington

Final Report
June 10, 1981

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The topic of the research was individual differences in dual task performance. It addressed the basic question: Is performance on multi-component tasks predicted by performance on the individual components performed separately? In the first series of experiments, we used a dual task involving memory and verbal processing components to predict a psychometric measure of verbal ability. Single and dual task performance were found to be highly correlated. The two types of measures predicted performance on the criterion verbal ability measure equally well. In a

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second experimental series, we compared ability to detect visual and auditory targets in single-channel, focused attention, and dividied attention conditions. Performance in the single channel conditions predicted performance in focused and divided attention conditions almost perfectly. In neither of these two types of experiments did we find evidence for a time-sharing ability. Finally, we used performance on a simple secondary task executed during an easy primary task to predict performance on a more difficult version of the same primary task. In this case, dual task performance provided information not available from the single task counterpart. The "easy-to-hard" prediction technique was found to be a successful method of predicting performance on difficult tasks.

The theoretical basis of this research was provided by a "general resource" theory of attention, in which all mental processes are seen as drawing on the same pool of attentional capacity. During the contract period, a more explicit model of inter-task interference was developed. This model, which we have called the Production Activation Model, will provide the basis for research under the new contract #N-00014-80-C-0631.

This report summarizes the research carried out under contract #N-00014-77-C-0225. All of the studies reported here have been described in previous technical reports or publications. The purpose of this document is to summarize the results and to provide a reference for specific sources.

BACKGROUND

During the 1970's, a number of psychologists began to relate the ability concepts derived from psychometric testing to the process concepts developed by cognitive psychologists. In this laboratory, we adapted a number of experimental tasks to yield individual measures of the speed and accuracy of various cognitive processes (Hunt, 1978a; Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975). These measures were correlated with standardized measures of academic ability. Modest correlations were found between a number of process and ability measures. Most notably, a relationship was found between verbal ability and speed of access to information in long-term memory. This finding has been replicated by a number of other investigators (Goldberg, Schwartz, & Stewart, 1977; Jackson & McClelland, 1979; Jackson, 1980; Keating & Bobbitt, 1978). Our work on the relationship between cognitive processes and verbal ability is summarized in Technical report #1 (Hunt, 1978b).

The major thrust of the effort to relate cognitive and psychometric measures has been to analyze complex psychometric abilities in terms of simpler and better understood cognitive

processes. For example, the typical psychometric measures of "verbal ability" combines scores on vocabulary, reading comprehension, and several other subtests. We wanted to discover the extent to which speed and accuracy of various simple mechanistic cognitive processes was related to performance on ability measures. Such an approach complements attempts to analyze complex task performance by breaking the tasks themselves into discrete stages (Sternberg, 1980).

ONR Contract #N-00014-77-C-0225 extended the idea that individual variation in complex cognitive processes could be explained in terms of variability in simple components of those processes. Previously we had asked whether the speed and acuracy of simple processes would predict ability scores. In this research, we asked whether the effort required by the simple tasks would predict performance on the more complex tasks. In many cases, complex intellectual tasks require that a person do two or more things at once. For example, mental arithmetic requires a person to hold partial results in memory while computing later results. If the person's total mental capacity is required to hold partial results in memory, then little capacity will be available to make further calculations. In this case, neither speed nor accuracy of the separate memory and computations processes would be sufficient to predict performance on the complex mental computation task. Some measure of the effort required by the component tasks would also be required.

The idea of 'mental effort' is closely related to the notion

that it is difficult to attend to several things at once. A conceptually simple model of attention as the expenditure of mental capacity was put forward by Moray (1967), and later by Kahneman (1973), and extended by others (Navon & Gopher, 1979; Norman & Bobrow, 1975). According to Kahneman, all mental processes draw from a single pool of mental resources, called 'attentional capacity.' Two simultaneously performed mental tasks interfere with one another if their combined attentional demands exceed the person's total attentional capacity. We will refer to this as the 'general resource model' of attention. In our research, we have applied the general resource model to the field of individual differences. Suppose that people vary in their characteristic level of attentional capacity or in the efficiency with which they perform specific tasks. To what extent will this determine their relative performance on various cognitive tasks?

The idea that attentional factors might be a source of individual differences led us to propose two lines of research. In the first, we asked whether performance on the two component tasks performed separately would predict performance on the same two tasks performed simultaneously, and further, whether performance in the dual-task situation would be more highly related to complex cognitive ability measures than performance on the components. In the second line of research, we tested what we have called the 'easy-to-hard prediction' hypothesis. According to this hypothesis, performance on a secondary task executed during the easy version of a complex primary tasks should predict

performance on a harder version of the same primary task.

SINGLE AND DUAL TASK MEASURES AS PREDICTORS OF VERBAL ABILITY

Two or our first studies of individual differences in attentional factors developed from an earlier interest in predicting verbal ability. We reasoned that many complex verbal tasks require that people hold verbal information in memory while encoding and manipulating new information. For example, the noun phrase of a sentence must be held in memory while the verb is encoded and processed. Each paragraph of an essay must be interpreted in light of the information retained from earlier paragraphs. Thus it seemed that a) both linguistic processing the verbal short-term memory should be important in predicting verbal ability; and b) the ability to carry out both functions simultaneously might be more important than the ability to carry them out in isolation.

We tested these hypotheses in two experiments. They are described in Technical Report #2 (Lansman, 1978). In these experiments, subjects were asked to perform two tasks: a rote recall task and a sentence verification task. In the dual task conditions, a list of items was presented, and while these items were being retained in memory, the subject was asked to respond 'true' or 'false' to a series of sentence verification items (e.g., "Plus is above star. $\overset{+}{\star}$ "). Finally, the memory items were recalled. In the single task conditions, the recall and sentence

verification tasks were performed separately. We reasoned that if subjects differed either in their total attentional capacity or in the efficiency with which they performed either recall or sentence verification tasks, then these differences would be reflected in dual but not single task performance. In that case, dual and single task measures would be imperfectly correlated, and dual task measures might be more strongly related to complex measures of verbal ability.

In fact, single and dual task measures were quite highly correlated, and the patterns of correlations between the two types of tasks and the criterion ability measures were almost identical. The experiments provided no evidence for an attention-related 'time-sharing' factor. Single and dual task measures were equally accurate in predicting verbal ability.

These studies indicated that a dual task combining rote memory and linguistic processing does not improve prediction of verbal ability over that provided by single task measures. There are several studies in the literature in which subjects were asked to perform a number of tasks both separately and in combination (e.g., Jennings & Chiles, 1977; Sverko, 1977). These studies were motivated by the hypothesis that there is a general ability to do two things at once and that this ability should manifest itself in dual task performance. In fact, no general time-sharing factor emerged in the analysis of the correlations among dual and single task measures. Thus, our results were consistent with a number of other studies in suggesting that there is no general time-sharing

factor, and that in many cases dual-task performance is quite well predicted by performance of component tasks.

A recent study by Daneman and Carpenter (1980) calls this conclusion into question. In their study, memory and verbal processing tasks were combined in a slightly different way: Subjects were asked to remember the final word in each of a series of sentences that they were reading for comprehension. Thus, in their dual task, memory and verbal processing tasks were integrated. Daneman and Carpenter found a very high correlation between accuracy of recall and reading ability. In contrast, we and others (Lansman, 1978; Palmer, MacLeod, Hunt, & Davidson, Note 1; Perfetti & Lesgold, 1977) have found virtually no relationship between rote memory and verbal ability in the college population. If the Daneman and Carpenter finding proves replicable, it suggests that verbal ability, or at least reading ability, is related to the ability to combine memory and verbal processing, but that the relationship is only evident when the memory and processing components are closely integrated. As the Daneman and Carpenter study used a very small sample of highly selected people, replication of their results is clearly in order.

FOCUSED AND DIVIDED ATTENTION

In the research discussed so far, 'time-sharing' has been used to refer to a subject's ability to divide attention between two competing tasks. Time-sharing ability may also refer to the

ability to divide attention between two competing channels of information. We investigated this ability using dichotic listening and visual search tasks. If there is an ability to divide attention between two sources of information, then we would expect performance in a single channel condition to be an imperfect predictor of performance in a divided attention conditions. We might also expect the ability to divide attention between the two ears to be related to the ability to divide attention between two visual locations. Our research on the ability to divide attention between two channels of information described in Technical Report #9 (Poltrock, Lansman, & Hunt, 1980).

In a large study of individual differences in the ability to divide and focus attention, we asked subjects to perform both dichotic listening and visual search tasks. In both cases, they were asked to press a key when they heard or saw one of a set of target letters. For each modality, there were three conditions: single channel (letters were presented to a single ear or at a single location), focused attention (letters were presented at two locations, but all targets occurred in a single location), and divided attention (targets could occur at either of two locations). The dependent measures were reaction time and accuracy in detecting target letters. Although reaction times were considerably slower and responses less accurate in focused and divided than in the single channel condition, performance in the three conditions was very highly correlated within modality.

In other words, performance in the single channel condition predicted performance in the other two conditions almost perfectly. The LISREL program for analysis of covariance structures was used to fit several models to the data. A model containing one factor for reaction times to auditory stimuli and a second factor for reaction times to visual stimuli provided a very good fit. The visual and auditory factors were correlated with each other (r = .61). No separate factors corresponding to the ability to divide or focus attention were required to explain the data.

In summary, the conclusions drawn from the study of divided and focused attention were similar to the conclusions drawn from the study of time-sharing between competing tasks: There was no evidence that the ability to divide attention between two tasks was an important source of individual differences in performance. In both cases, performance in the single channel or single task condition predicted performance in the divided attention or dual task situation almost perfectly.

In developing the dichotic listening task, it was possible to study an issue which, though not directly concerned with individual differences, has some interesting implications for attentional theory. Previous studies comparing single channel and divided attention conditions in the auditory modality had commonly used what Schneider and Shiffrin (1977) have called 'consistent mapping conditions,' which minimize demands on attentional capacity. Throughout these experiments, one set of stimuli were

designated as targets and another set as distractors. It had been found that accuracy is about equal in single-channel and divided attention conditions as long as two stimuli do not occur simultaneously on the two channels. (See, for example, Ostry, Moray, & Marks, 1976.) We wondered whether this finding was related to the reduced attentional demands of the consistent mapping condition. Accordingly, we had subjects perform the dichotic listening task under both consistent and varied mapping conditions. The consistent-varied distinction proved to be as important in auditory target detection as Schneider and Shiffrin had shown it to be in visual search. Reaction time was much faster and accuracy higher under consistent mapping conditions. Furthermore, there was a much smaller memory set size effect under consistent mapping conditions, and this effect decreased over practice. These results are reported in more detail in Technical Report #9 (Poltrock, Lansman, & Hunt, 1980), and also in a report that is in publication (Poltrock, Lansman, & Hunt, in press).

EASY-TO-HARD PREDICTION

A major part of our research on this contract has concerned what we have called 'easy-to-hard prediction.' Like the research described above, this technique involves examination of individual differences in dual-task performance. However, the rationale is somewhat different. When two tasks are performed simultaneously, they compete for attentional capacity. If one of the tasks is designated as 'primary' and the other as 'secondary,' then the

primary task should receive top priority in the allocation or resources, and the secondary task should receive what is left. Secondary task performance should therefore reflect spare capacity available during performance of the primary task. We reasoned that spare capacity available during performance of an easy primary task should be available for performance of a harder version of the same primary task. Thus performance on a secondary task during an easy primary task should predict performance on a harder version of the same primary task -- the 'easy-to-hard prediction.'

The rationale behind the easy-to-hard prediction technique is derived more formally in Technical Report #8 (Hunt & Lansman, 1980). A revised version of this report is also to be published in a book edited by R. Sternberg (Hunt & Lansman, in press). In that paper, we assumed that performance on any task is a function of two individual parameters: a structural parameter specific to that particular task, and a resource parameter reflecting the amount of general attentional resources available to the task. We showed that performance of the secondary task during the easy primary would provide information concerning the resource parameter that was unavailable from single task performance. Since the derivation was done in terms of classic information theory, it made no assumptions concerning the form of the relationship between performance and resources available.

The easy-to-hard prediction technique has been tested in several experiments, which are described in Technical Reports #2

(Lansman, 1978), #4 (Hunt, Lansman, & Wright, 1979), and #7 (Lansman & Hunt, 1980). In several of these experiments, the primary task was a continuous paired associate learning task in which subjects were asked to keep track of two to seven letter-number pairs, while the secondary task required subjects to respond as quickly as possible to a simple probe stimulus. Reaction time to probes that occurred during an easy version of the paired associate primary task predicted performance on a harder version of the paired associate task. In another experiment the primary task was a spatial memory task in which subjects were asked to judge whether a spatial pattern was identical to a standard pattern and the secondary task again involved response to a probe stimulus. In this experiment, reaction time to the secondary probes did not significantly improve prediction of performance on the hard version of the primary task. The differences between the paired associate and the spatial memory tasks seemed to be that resource availability was the limiting factor in performance of the paired associate but not the spatial memory task.

The easy-to-hard technique was also used in an experiment involving a slightly different paradigm, described more fully in Technical Reports #4 (Hunt, Lansman, & Wright, 1979) and #8 (Hunt, 1979). (Report #8 has also been published in the British Journal of Psychology (Hunt, 1981)). In this case, the primary task was the Raven Progressive Matrix Test and the secondary task required subjects to exert a constant pressure on a lever. On the Raven

Test, each item is more difficult than the previous item. Performance on the secondary task during any given Raven item was found to provide information concerning which subjects were about to make a mistake on the succeeding item. Interpreted within the general resource theory, the results showed that those subjects whose total capacity was required by one problem (producing poor performance on the secondary task) were likely to fail to solve the succeeding, more difficult problem.

In earlier sections of this paper, we reported several experiments in which performance in dual-task conditions was very accurately predicted by performance in single task conditions. Here we are arguing that performance of a simple secondary task does indeed provide information unavailable from performance of the single-task counterpart. How can this contradiction be resolved? The issue is discussed in Technical Report #8 (Hunt & Lansman, 1980). Performance on most complex tasks reflects both structural parameters and resource limitations, whether the tasks are performed in single or dual-task conditions. If this is the case, then we would expect single and dual task performance to be highly correlated since they both reflect the same underlying parameters. However, some simple tasks, such as response to a single probe stimulus, are 'data-limited' under single task conditions. That is, performance of these tasks would not be improved if additional resources were allocated to them. However, under dual-task conditions, these same tasks become resource-limited! Performance is inversely related to the amount

of resources drawn off by the primary task. In this case, performance in the single-task conditions reflects only structural parameters specific to the task, while secondary task performance reflects both structural and resource parameters. The result is that single and dual task performance are not highly correlated. Dual task performance provides information concerning resources available during the primary task. This information can be used to predict performance on a harder version of the same primary task.

A THEORY OF ATTENTION

The theoretical basis of the easy-to-hard technique was a simple theory of attention, in which all mental processes were seen as drawing upon a general attentional resource. The strength of such a theory lies in its simplicity and ability to summarize a vast amount of data on dual-task interference. Its weakness is the fact that 'attentional capacity' is a strictly hypothetical construct, and is not tied to any other physiological or even theoretical entity. Implicit in the general resource theory is an analogy between attentional resources and physical energy sources such as electricity or water power. But while energy resources are well-defined within theories of physics, attentional resources are defined only by analogy.

During the contract period, we have developed a more explicit model of attention, called the Production Activation Model. The theory is described in detail in a paper by Hunt (in press). It

is closely related to models of thinking developed in the fields of cognitive science and artificial intelligence. However, the Production Activation Model goes beyond these theories in that it deals with the problem of how the organism handles competing stimuli. Within the model, mental activity consists of the execution of a series of productions. These productions are stored in long-term memory. It is the function of a decision mechanism to determine the order in which the productions will be executed. At any given moment, the external world and the contents of short-term memory form a stimulus configuration. This configuration activates a number of productions. Which production will actually be executed depends upon two things: a) the match of the stimulus configuration to the pattern specified by the production, and b) the baseline activation level of each of the productions. The baseline activation level of a production is strongly influenced by the productions that have preceded it. The execution of one production biases the system toward the execution of certain other productions in such a way that a well-practiced task consists of a chain of productions that is usually executed as an unbroken sequence. Within this model, structural interference results from competition for one of the effectors involved in the execution of productions. Central interference results from competition for access to the decision mechanism.

Within the Production Activation Model, the decision mechanism fills the role that 'general attentional capacity' filled in the General Resource Model. Both are strictly

theoretical concepts. The difference is that the function of the decision mechanism is more fully specified within the Production Activation Model. The model thus allows us to formulate more specific questions concerning dual task interference. These questions concern the role of practice, task priority, expectancy, and several other variables. Our new contract, #N-00014-80-C-0631, was formulated within the framework provided by the Production Activation Model. Under this contract, we have proposed two main lines of research. We will a) develop a computer simulation of the Production Activation Model, and b) empirically investigate some the the questions raised by the model. The empirical investigation will provide data against which to test the computer simulation.

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